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A SIMPLE AND LOW COST METHOD FOR RAPID ASSESSMENT OF AIR VOIDS IN HARDENED CONCRETE

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ABSTRACT

Presented herein is a new technique and a low cost method to estimate the ratio of air voids in hardened concrete within 30 minutes using available flatbed scanner, black inkjet, personal computer and image treatment software This test method includes contrast enhancement steps ensuring black ink (air voids) in gray concrete (aggregate and paste), image acquisition and computer analysis of scanned image. It is applied on specimens of normal concrete (NSC), high strength concrete (HSC) and high strength concrete with Polypropylene fibers. Results obtained are compared with the peer values of wet concrete ratios of air voids. As compared with other ASTM procedures, it is concluded that this method may have superiority over other methods due to its simplicity, low cost, less time and no need of skilled technicians. It is recommended to be used for hardened concrete as well as rock specimens.

Keywords: Concrete; characterization; image processing; air voids; scanning

1. INTRODUCTION

The durability and performance of Portland cement concrete varies with the volume of cement, sand, aggregate and water used in a mixture, as well as its air content. The function of entrained air voids in concrete for providing freeze-thaw durability has been known since the 1940's [1]. One of the first attempts to characterize the spacing of air voids was by Powers [2], which was the basis for the American Society for Testing and Materials ASTM C 457 "Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete " [3]. This method is widely recognized as a time consuming procedure that requires a skilled operator. The variability of test results using this method have been investigated by many researches [4 - 6].

Nowadays, image display and processing no longer require any special hardware. With the advent of graphical user interfaces, image display has become an integral part of a personal computer. Besides the display of gray scale images with up to 256 shades (8 bit), also true-color images with up to 16.7 million colors (3 channels with 8 bits each), can be displayed on inexpensive PC graphic display systems with a resolution of up to 1600×1200 pixels. Consequently, image processing only needs a digitized image that can be obtained by digital

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video or still camera. This has permitted the development of automated system for air void analyzing. The most notable of the current automated systems is available from the independent firm Concrete Experts International (CXI) of Copenhagen Denmark. The CXI system is marketed and commonly known as the Rapid Air 457 automatic air void analysis system. This system performs air void analyses with the aid of a grayscale camera attached to a computer controlled motorized control stage as shown in Figure 1. Further researches have used flatted scanner for acquisitioning the surface image of hardened concrete and then processing them with computer (Figure 2). The flatbed scanner method developed by Michigan Technological University [7], works on the principle of contrast enhancement where non-air portions of the surface appear black and air voids appear white. Prior to scanning a sample, 8 stickers are placed along the perimeter of the polished surface. They prevent the surface from resting directly on the glass plate of the scanner to avoid scratches. Contrast enhancement is achieved by drawing overlapping parallel lines with a wide-tipped black marker. After the ink dries, a few tablespoons of 2 micrometer white powder are worked into the surface using the flat face of a glass slide. A razor blade is used to scrape away excess powder, leaving behind powder pressed into voids. Residual powder is removed by wiping with a clean lightly oiled fingertip. A fine-tipped black marker is used to darken voids in aggregates. Image is collected with an 8-bit grayscale, 3,175 dpi flatbed scanners and then processed by computer. A good comparison of these two techniques is given is given by Karl W. Peterson et al [8 - 10].

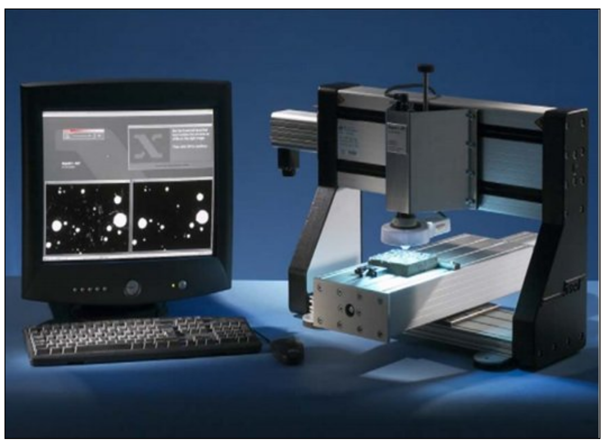

Figure 1. The Rapid Air 457 automatic air void analysis system

The low cost method for the determination of the percentage of air void in hardened concrete described in this paper is also based on flatted scanner. It differs from the techniques previously described in the simple preparation before scanning. It use black inkjet to fill the void in the concrete so contrarily to the other methods, after simple preparation the air void appear in black and the paste and aggregates appear in gray. The used black ink normally destined for inkjet printer provides many advantages. Its viscosity allows a better penetration in all accessible voids. Inkjet pigments are nano grade polymeric dispersed pigments there average particles size is less than 100nm [11]. Its particle size is smaller than the particle size of white powder 2µm [12, 13] and allow to analyze nano bulbs of air void.

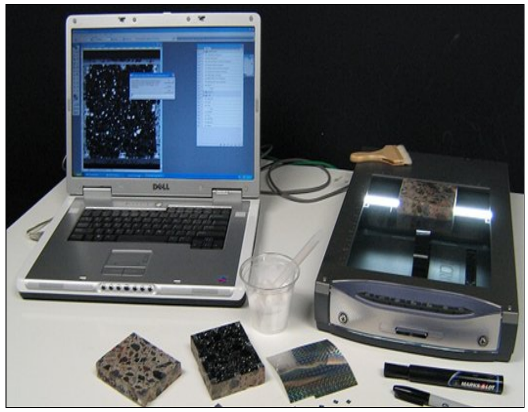

Figure 2. Instrument setup for the flatbed scanner method [13]

2. MATERIALS AND EXPERIMENTAL METHODS

2.1 Materials used

Aggregate used was of crushed limestone there properties are given in Table 1. Commercial Portland cement of 42.5 MPa grade, produced in Jordan as CEM I cement were employed. The chemical composition and physical properties of the cement are given in Table 2. Silica fume (ASTM C-494 F type) and polypropylene fiber (PP fiber) were used. Physical properties of PP fibers are given in Table 3

Table 1: The results of aggregates tests

Grain size (mm)	**Sieve size (mm)**							**Specific gravity**	**Unit weight (kg/m^3)**	**Water abs. ratio 24 h (%)**
	12.5	**8**	**4**	**2**	**1**	**0.5**	**0.25**			
0–4	100	100	97	82	69	41	29	2.46	1705	1.62
4–12.5	99	46	2	1	0	0	0	2.75	1617	1.05

2.2 Mixture proportioning and casting details

The gradations of aggregate used to obtain the three types of concretes designated by normal strength concrete (NSC), high strength concrete (HSC) and high strength concrete incorporating polypropylene fibers (HSC-PP) were the same. In the mixture proportioning of normal strength and high strength concretes, water to cement ratios of 0.45 and 0.30 were used, respectively. In the production of high strength concrete, silica fume was added (10% of weight of cement) and superplasticizer admixture was used. The detailed mixture proportion of these concretes is given in Table 4.

In mixing concrete, a concrete mixer having 80 liter capacity and inclined axes was used. The course and fine aggregates were weighed and placed into the concrete mixer moistened in advance and mixed for 3 min with the addition of saturation water, for 3 min with the addition of cement and silica fume. The superplasticizer was then mixed thoroughly with the mixing water and added to the mixer.

Table 2: Characteristics of cement

Physical test results		**Chemical test results %**		**Composition %**	
Initial setting time	2:25	CaO	58.80	C_3S	61.19
Final setting time	4:20	SiO_2	21.70	C_2S	11.09
Specific surface (cm^2/gr)	2810	Al_2O_3	6.10	C_3A	7.92
Specific gravity	3150	Fe_2O_3	3.60	C_4AF	10.39
Residue on 200 µm (%)	1.0	MgO	3.60		
		SO_3	3.00		
		K_2O	0.72		
		NaO	0.44		
		Loss of ignition	1.50		

Table 3: Physical and mechanical properties of fibers

Diameter (µm)	50
Length (mm)	20
Aspect ratio	1000
Relative density(g/cm^3)	0.91
Ignition temperature (ºC)	600
Melt temperature (ºC)	165

Table 4: Concretes mixture proportion

Composition	**NSC**	**HSC**	**HSC-PP**
Cement (kg/m^3)	500	500	500
Sand (kg/m^3)	1125	1220	1220
Gravel (kg/m^3)	1470	1450	1450
Silicate fume (kg/m^3)	-	50	50
Polypropylene fibers(kg/m^3)	-	-	1.5
Water (liter)	250	204	204
Superplasticizer (%)	-	0.03	0.03
Water to binder ratio	0.50	0.37	0.37

Fibers were dispersed by hand in the mixture to achieve a uniform distribution throughout the concrete, which was mixed for a total of 3 min. For each concrete mix, the Air Content of freshly mixed concrete was first measured according to ASTM C 231-04 Standard Test and then concretes were cast in steel moulds and compacted on a vibrating table. Cube specimens of 100 mm size were used for strength determination, and cubes of 50 mm where cast for air void analyzing. After demolding at one day, the specimens were cured in water at 20 until 28-day age and then cured in air with temperature of 20°C and 50% R.H.

3. SAMPLE PREPARATION AND SCANNING PROCEDURES

3.1 Equipment and Needed Materials

This is a new technique and a low cost method to estimate the ratio of air voids in hardened concrete within 30 minutes using available flatbed scanner, black inkjet, personal computer and image treatment software in addition to polishing paper, brushes and solvent. Documented description of the used materials, equipment and operation are shown in Figures 3 through 6.

3.2 Surface contrast enhancement

The objective of the contrast enhancement was to produce a surface where the voids in the concrete are colored black while the remaining phases (cement paste and aggregate) were colored light gray. This contrast allows to clearly distinguishing between the portion of the sample that are voids and the non-voids in the scanned image. The steps used in this study were as follows:

1. The surface of specimens was polished with an adhesive backed fine grit fixed SiC paper. This type of paper is available in almost any store for building materials and accessories. Polishing residues were removed by a brush and blowing with compressed air. This step is done in order to eliminate all irregularity and to obtain a smooth surface.
2. With a painting brush, a thick layer of black ink was carefully deposed on the smooth surface to ensure that all void was filled with the ink and then left to dry.
3. After the ink dried, the concrete surface is cautiously cleaned with a cloth soaked with solvent ink to reduce the black level of the smooth surface that takes the color gray to light brown while voids stay black.
4. Specimens are then ready to be scanned.

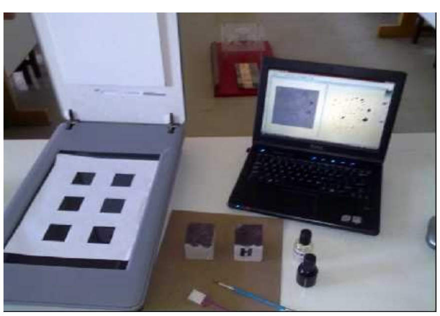

Figure 3. Scanner and computer

Figure 4. Specimens to be scanned

Figure 5. Materials used

Figure 6. Painting concrete surface

3.3 Digital Image Collection

A high resolution flatbed scanner was used for images acquisitions. Image of the specimen was collected at 9600 x 9600 dpi (equivalent to pixel resolution of 2.5 x 2.5 microns). Specimens were placed on sheet of paper in witch six square windows of 40 x 40 mm were pierced. This sheet of paper protects the glass surface of scanner and provides Landmarks around specimens for possible measures. Up to six specimens may be scanned together. Figure 7 shows a typical image as obtained in one scan operation.

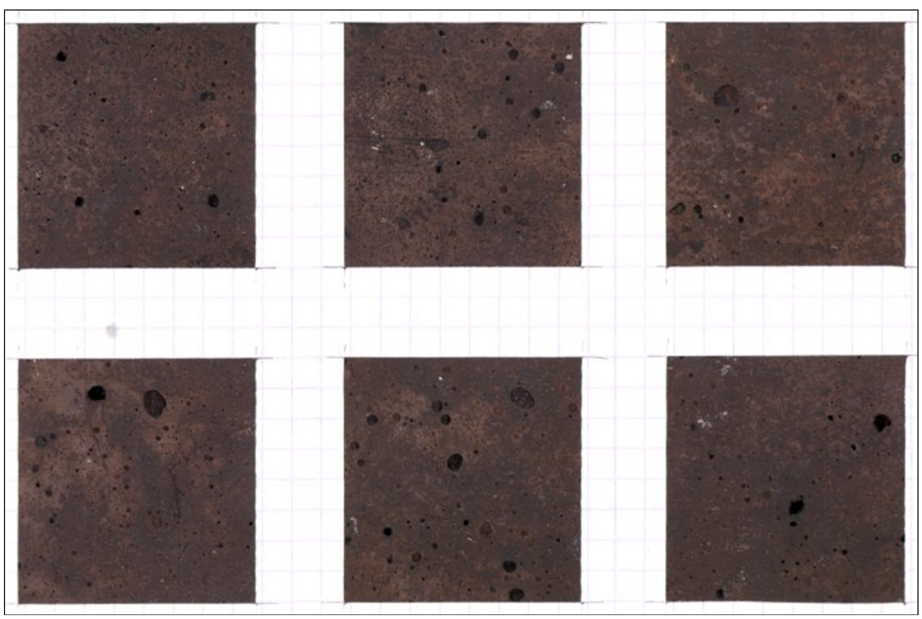

Figure 7. Typical image as it obtained for normal strength concrete scanning

3.4 Digital Image processing

Digitized image (JPEG format) were stored in a computer and then analyzed via image treatment software. The computer used was a laptop equipped with a processor Core 2 Duo 1.6 GHz and running under windows Vista. The software used for image processing was the “Jasc Paint Shop Pro version 7.04” Figure 8 shows a captured screen image during image processing. The captured images were first encoded in gray scale, then the function of histogram adjustment was used to enhance the black level, finally the image was segmented in two colors: the first one is black color that represents the air voids and the white color that represents the hardened concrete paste matrix and aggregates.

The percentage of air voids is then calculated automatically as the percentage of the black pixels in the total number of pixels of the image.

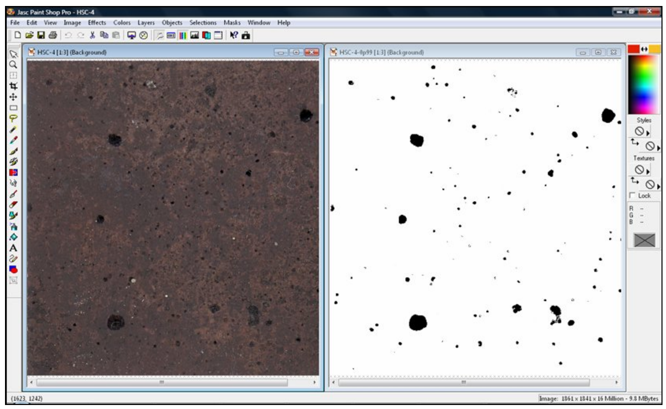

Figure 8. A captured screen image during images processing

4. RESULTS AND DISCUSSION

Table 1 shows the results of the six image processed of each concrete. The average values are compared to those measured on fresh concretes.

When the wet concrete specimens were sampled, the values of air voids were obtained by the method of ASTM C 231-04 on fresh concrete. The results of three specimens designated S1, S2, and S3 were recorded and averaged and compared with their peer results of hardened concrete obtained by the low cost proposed method and shown in Table 5. Compared results are also plotted in Figure 9.

Table 5. Air voids measured by Low Cost method and by ASTM C231-04

Concrete Type	**Value of air voids, %**							
	Low cost method				**ASTM C 231-04**			
	S_1	**S_2**	**S_3**	**Average**	**S_1**	**S_2**	**S_3**	**Average**
NSC	2.4	3.4	2.3	2.7	3.5	2.7	3.1	3.1
HSC	1.2	1.0	1.3	1.2	2,0	2,5	2,1	2.2
HSC-PP	5.2	5.7	6.3	5.7	4.8	5.4	5.1	5.1

This figure demonstrates that there is a very good agreement between these two procedures. Same result was reported by Karl W. Peterson et al. [12] based on evaluation of air content measurements in plastic concrete and in hardened concrete for four automated image analysis methods, and by the ASTM C 457 method.

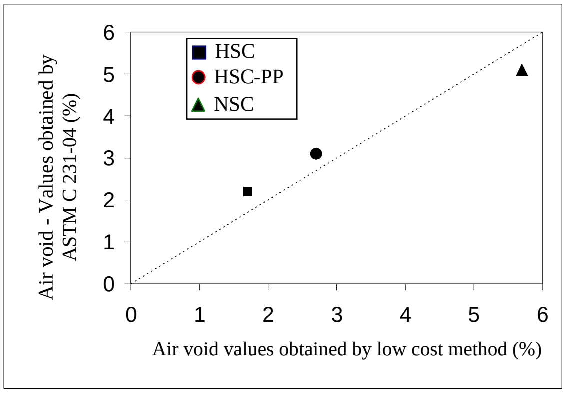

Figure 9. Values f air void abstained by ASTM C 231-04 versus values obtained by the low cost method

5. CONCLUSIONS

The proposed low cost method for the estimation of air voids in hardened concrete is applied to the three types of concrete, namely: normal strength, high strength and high strength with propylene fibers. Air void distribution is one of concrete durability indicator that needs to be apprised. The use of automated system as the Rapid Air 457 for air void appreciation seems fairly simple but it requires skilled labor. On the contrary and in the case of unavailable flatbed scanner methods, this method offers an inexpensive alternative for determining the air voids of hardened concrete.

The following conclusions may be drawn from this study:

1. The low cost method presented in this paper, is easy to apply and does not need specific materials, since all that is needed are a significant number of polished samples.
2. It gives a reasonable precision and its use can cover a wide range of air-void systems.
3. The low cost method will allow engineers to more simply monitor the quality of air void systems in concrete, comparing hardened concrete air-void systems to those projected by fresh concrete leading to more durable concrete and reducing testing costs.
4. This method does not require skilled labor and more effort and time.
5. It is anticipated that the presented technique could be applied to rock and/or rocklike specimens.

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REFERENCES

1. Kennedy HL. The function of entrained air in concrete, *Journal of American Concrete Institute*, **14**(1943) 529-42.
2. Powers TC. The air requirement of frost-resistant concrete, *Proceedings, Highway. Research Board*, **29** (1949) 184-202.
3. American Society for Testing and Materials, Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete, Designation: C 457-90, Philadelphia, PA, 1995.
4. Sommer H. The precision of the microscopical determination of the air-void system in hardened concrete, *Cement, Concrete, and Aggregates*, No. 2, **1**(1979) 49-55.
5. Saucier F, Pleau R, Vezina D. Precision of the Air Void Characteristics Measurement by ASTM C 457: Results of an Interlaboratory Test Program, *Canadian Journal of Civil Engineering*, **23**(1996) 1118-28.
6. Simon M. An Interlab Evaluation of the Variability in the ASTM C 457 Linear Traverse Method: Final Report, No. OR06-009/R198-006B, Missouri Department of Transportation Organizational Results, 83 p., December 2005.
7. Peterson KW, Sutter L, Van Dam T. Air Void Analysis of Hardened Concrete with a High-Resolution Flatbed Scanner, Proceedings of the 24th International Conference on Cement Microscopy, San Diego, California, 2002, pp. 304-316.
8. Carlson J, Sutter L, Peterson K, Van Dam T. An Update on Application of a Flat-Bed Scanner for Performing ASTM C 457, Proceedings of the 27th International Conference on Cement Microscopy, Victoria, British Columbia, Canada, 2005.
9. Peterson KR. Air-Void Analysis of Hardened Concrete: Helping Computers to Count Air Bubbles like People Count Air Bubbles - Methods for Flatbed Scanner Calibration Ph.D. dissertation, Michigan Technological University, April 2008.
10. Peterson KR. Air void analysis of hardened concrete via flatbed scanner M.Sc. thesis, Michigan Technological University, May 2001.
11. Jetcolour-Aqueous Inkjet Colorants and Dispersions, web page «http://www.jetcolou.com/products/jcw.html» accessed on June 17, 2009.
12. Peterson KW, Thaulow N, Baumgart CW, Furuichi H, Casper M, Jana D. A round robin test on measurements of air void parameters in hardened concrete by various automated image analyses and ASTM C 457 method. Proceedings of the twenty-ninth conference on cement microscopy Quebec City, PQ, Canada, May 20-24, 2007, pp. 34-69.
13. Jakobsen UH, Pade C, Thaulow N, Brown D, Sahu S, Magnusson O, De Buck S, De Schutter G. Automated air void analysis of hardened concrete - a Round Robin Study, Cement and Concrete Research, **36**(2006) 1444–52.